

Adaptive Laser Plasma Simulation (ALPS)

The goal of this project is to investigate the utility of parallel adaptive mesh refinement (AMR) in the simulation of laser plasma interaction (LPI). AMR enables efficient resolution of the widely varying scales encountered in computational models of LPI, including simulations of the ignition-scale configurations to be employed at the National Ignition Facility (NIF). The research code ALPS (Adaptive Laser Plasma Simulator) is being developed to explore new AMR algorithms and parallel implementation strategies for LPI.

Background

The ability to predict and control the interaction of intense laser light with plasmas is critical in the design of laser-driven fusion experiments. Early in the laser pulse, rapid ionization of the capsule and surrounding materials generates a dynamic, plasma-filled region. The pulse must continue to propagate through this region without substantial perturbation in order to achieve the desired energy deposition on the target. However, a variety of LPI mechanisms, such as filamentation and parametric instabilities, can affect the light propagation, and these LPI mechanisms can interact with each other in a highly complex manner.

In recent years, computational models have become an increasingly important complement to theoretical analysis and experimentation in LPI research. For example, several years ago the Plasma Theory Group in X Division at LLNL began developing a code called pF3D; this code has served as an essential tool in NIF design studies and other plasma physics investigations. A limitation of current LPI codes, however, is their

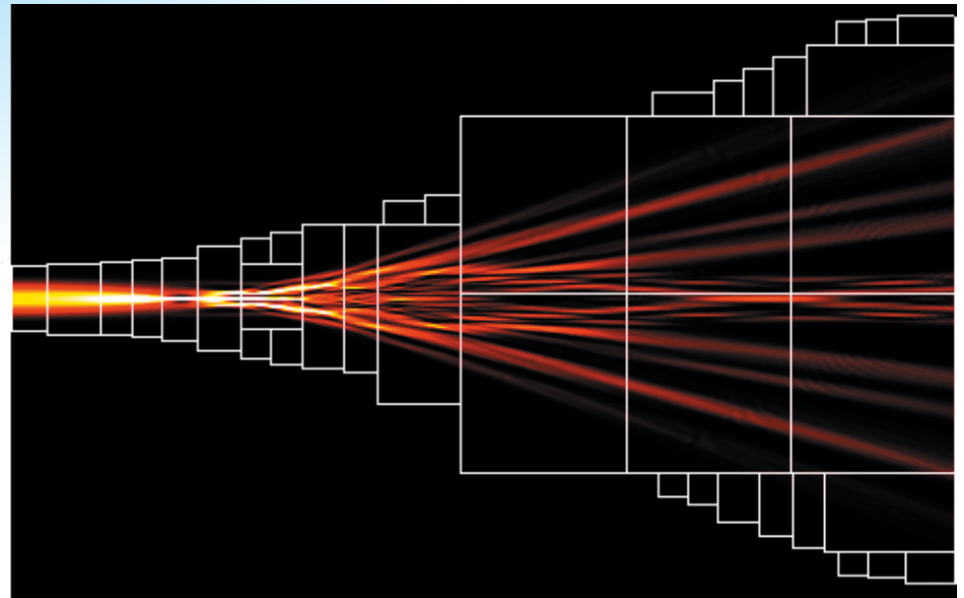


Figure 1. Adaptive mesh calculation of a filamenting beam.

reliance on uniform grids. For many problems of interest, the discrete resolution needed to compute LPI accurately in one part of the computational domain is much greater than that needed in the rest of the domain. This motivates our investigation of parallel AMR to increase the efficiency of LPI simulations by enabling computational resources to be applied only where they are needed. For example, as shown in Figure 1, fine computational grids (within the white boxes) can be employed to resolve a filamenting beam. The remainder of the plasma-filled region can be computed on a coarser grid

Approach

To investigate the utility of AMR in the simulation of LPI, we are developing a research code called ALPS (Adaptive Laser Plasma Simulator). In ALPS, the plasma is represented by an Eulerian fluid model that is discretized using a high-resolution, upwind difference method applied to the equations describing conservation of total mass, momentum and energy. The laser light propagation is modeled using a paraxial wave equation and implemented with a second-order finite-difference

algorithm. ALPS can simulate LPI problems in either two or three spatial dimensions.

Local mesh refinement is introduced into the ALPS discrete model using a block-structured refinement approach in which the computational domain is viewed as a hierarchy of refinement levels. Each refinement level is a disjoint union of rectangles and is properly contained in the next coarser level. The solution of the plasma and light equations on the grid hierarchy is accomplished through the integration of each system on individual refinement levels combined with synchronization steps to ensure consistency across refinement levels.

ALPS is being developed using the SAMRAI (Structured Adaptive Mesh Refinement Application Infrastructure) system currently under development in CASC. SAMRAI is a C++ class library that supports the development of parallel, structured AMR application codes.

Example: Simulation of crossed laser beams in a plasma flow

As an example, we consider a problem in which two laser beams cross in an

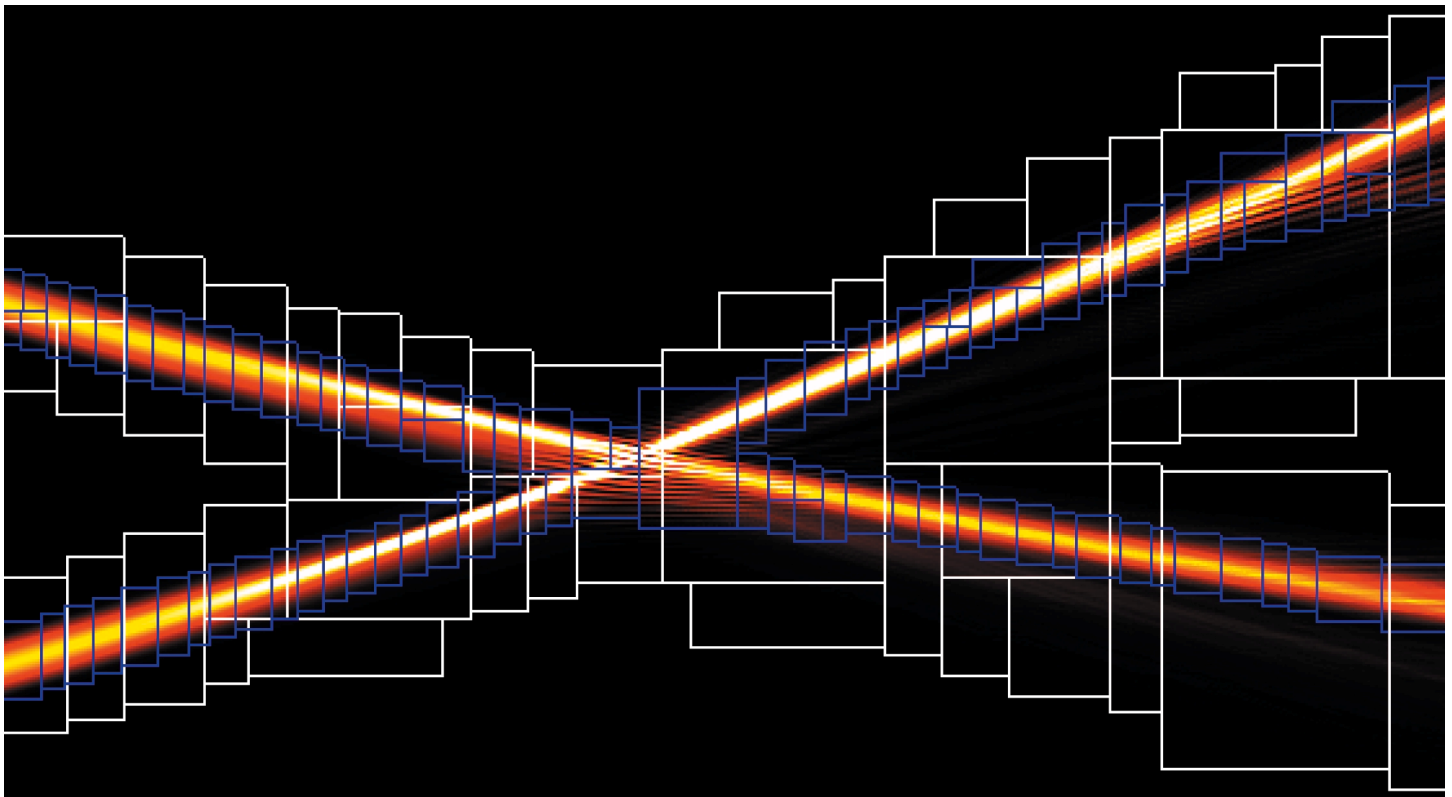


Figure 2. Adaptive calculation of light intensity for crossed beams in an expanding plasma. The white boxes indicate the first refined level and the blue boxes indicate the second and finest level.

expanding plasma. This represents an idealization of a physical experiment in which a foil is ionized by a separate heater beam in the vicinity of the crossed beams. Such problems are of potential relevance for NIF experiments, where the inner and outer beams will cross in regions of substantial plasma flow.

We model the initial conditions as an isothermal, quasineutral CH plasma freely expanding upwards in a computational domain of size $640\text{ }\mu\text{m}$ by $500\text{ }\mu\text{m}$. The initial number density and velocity distributions are specified analytically as an isothermal expansion fan such that, on the vertical centerline, the plasma velocity is the ion acoustic velocity and the number density is one-tenth of the critical density. The initial ion and electron temperatures are 0.5 keV and 1 keV , respectively.

Two $1.06\text{ }\mu\text{m}$ wavelength laser beams instantaneously enter through the left boundary at the initial time. Each beam has a cosine-squared amplitude variation over a $40\text{ }\mu\text{m}$ wide spot and a maximum intensity of $5.1 \times 10^{14}\text{ W/cm}^2$. The beams propagate at 15°

angles to the horizontal so as to intersect, in the absence of plasma, at the center of the domain.

Since little happens outside the immediate neighborhoods of the beams, the coarsest level is sufficiently resolved by a 256×160 cell grid. An additional level of refinement by a factor of eight is initially imposed to provide resolution sufficient to propagate the beams in the correct directions. Subsequently, this level adaptively refines on intensity levels above $5 \times 10^{12}\text{ W/cm}^2$, and a second level of refinement by a factor of two resolves regions where either the intensity exceeds 10^{14} W/cm^2 or intensity gradients exceed 10^{19} W/cm^3 .

The light intensity computed by ALPS is plotted in Figure 2, where white denotes the highest intensity and black the lowest. The white boxes indicate the first refined level and the blue boxes indicate the second and finest level. Two major effects are present. First, since light refracts due to gradients in the plasma density, both beams can be seen to deflect upward in the

direction of lower plasma density. Secondly, an interference pattern is produced in the overlap region where a resonant coupling exists between the light beat wave and an ion acoustic wave. This resonance results in a transfer of energy between the beams, as seen in Figure 2. The ability to use local mesh refinement to sufficiently resolve the overlap region is essential to ensure that the resonance is not detuned by dissipation in the numerical scheme.

Collaborations

We collaborate with R. L. Berger, A. B. Langdon, C. H. Still, E. A. Williams (Plasma Theory Group, X Division), B. I. Cohen and L. M. Divol (M Division) at LLNL.

For additional information about ALPS, contact: Milo R. Dorr, (925) 422-1064, milodorr@llnl.gov, F Xabier Garaizar, (925) 423-1521, garaizar1@llnl.gov, or Jeffrey A. F. Hittinger, (925) 422-0993, hittinger1@llnl.gov.